SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

ON

FLUCTUATIONS OF LEVEL

IN THE

NORTH AMERICAN LAKES.

BY

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FLUCTUATIONS OF LEVEL

IN THE

NORTH AMERICAN LAKES.

In the year 1838 a remarkable rise was observed in all the Lakes, since which date I have neglected no opportunity to collect information concerning the fluctuations of level that occur in these waters. For Lake Erie, by the assistance of various observers to whom I have given credit in the proper place, I am now able to present daily measurements for four entire though not consecutive years, besides registers for parts of several years, and also to give some statistical tables for other Lakes.

The observations show three kinds of fluctuation.

1. A general rise and fall, extending through a period of many years, which may be called the *secular variation* of level, having no regular period of return, and depending upon peculiar combinations in the meteorology of the country drained by the tributaries to the waters of the great Northern Lakes.

2. An annual rise and fall within certain limits, the period of which is completed in about twelve months. This, which is caused by changes of the seasons within the year, and can be predicted with much certainty, may properly be called the *annual variation*. It occurs regularly, without reference to a general height of the waters.

3. A sudden, frequent, but irregular movement, varying from a few inches to several feet. This is of two kinds: one due to obvious causes, such as winds and storms; another resulting from rapid undulations in calm water, the cause of which is not yet satisfactorily explained. Both classes may be styled *transient fluctuations*.

In this paper I shall do little more than classify the statistics which I possess. Meteorological registers for the Lake regions, owing to the recent settlement of the country, are very scarce; and such as are to be found do not extend through many years. The Army Meteorological Reports embrace the greatest length of time, but reach no farther back than the year 1822.

In the reports of the regents of the University of New York there is much valuable information on meteorology in general; a part of which refers to the basin of the great Lakes. Half a century hence, when, by means of the records now established, a good annual abstract of the temperature, rain, and cloudiness of the region can be made out, I have no doubt that there will be found a direct correspondence between the secular fluctuations of the level of the Lakes and the meteorology of the surrounding country.

When a wet, cold, and cloudy year is succeeded by another of the same character, the reservoirs, into which so many rivers, creeks, and streamlets discharge their waters, gradually fill up. A contrary combination, viz: a series of dry, warm, and clear seasons, by diminishing the supply and increasing evaporation, will produce a visible depression of the surface of the Lakes. To discuss thoroughly the phenomena of fluctuation we need daily registers, kept at different and distant places on each Lake, for a period of at least twenty-five years. It is probable that within that length of time the seasons complete a cycle, and return to pass again through a similar course of changes. To establish and continue such registers would, however, require the assistance of the government. The Topographical Bureau has required its agents at the Lake harbors, in some cases, to keep water tables; and these form the most minute and reliable information we possess. This corps, however, is engaged in harbor constructions only at irregular intervals, and consequently leave in their records many blank spaces. Government has, however, through its light-house keepers, the means of procuring perfect registers of water levels on all the Lakes, with the least possible expense; and there would be little difficulty in pointing out numerous practical results that would justify such a system of observations, without regarding the unseen benefits that always follow the acquisition of scientific knowledge. In this case there are important benefits accruing to commerce, not requiring demonstration. The soundings, made in the prosecution of the hydrographical survey of the Lakes, to be reliable marks for knowing the depth, should be referred to a well determined stage of water. Docks, warehouses, and harbor channels derive their value from being at all times accessible to vessels. The tables now presented show extreme changes of level of seven feet; and from the average of entire months, in different years, a difference of five feet three inches.

There are some vessels on the Lakes that draw more than nine feet, and, therefore, a dock constructed at the time of high water, into which a vessel of this draught could enter, would require between five and six feet of dredging, in order to be used during low water.

As a question of science and of utility, the whole subject has engaged the attention of prominent men. De Witt Clinton and General Cass, among others, have bestowed upon it the most careful study. General Henry Whiting, of the army, while residing at Detroit, at and subsequent to the war of 1812, kept the first registers to which we can refer. Dr. Douglass Houghton, the lamented geologist of Michigan, made it one of the objects of his examination during his short but active life.

I have condensed, from all sources within my reach, information respecting the state of the waters since the settlement of the Lake country. This is put into a tabular form; but is in many cases based upon general report, upon tradition, and the memory of living witnesses, but latterly upon measurements. The authorities are given on the same sheet, so that the value of what it contains may be properly estimated.

Since 1838, reliable measurements have greatly increased. That which I have given for Lake Erie is an abstract of the registers at three ports—one at each end of the Lake, and one near the middle or widest part.

At Detroit, Messrs. A. E. Hathan and S. W. Higgins made use of the base of the hydraulic tower connected with the water-works of that city as a bench mark, counting downwards to the surface of the water in the river. At Cleveland the high water line of June, 1838, has been used as zero, also reckoning downwards. This line was two feet below the surface of the east pier, at the south end of the steps leading up the parapet wall. The mitre sill of the guard lock at Black Rock was at first used by the engineers of the State of New York on which to register the depth of water. When the enlargement of the Erie Canal was commenced, Mr. John Lothrop, C. E., transferred the measurements to the bottom of the canal, at Buffalo, which is one foot below the mitre sill of the guard lock. (See Plate I., No. 1.)

As the records at different places are but seldom of the same dates, it is not easy to bring them into comparison with each other. To effect this, in the only manner they admit of, I neglect the descent of the Detroit River from that city to the Lake, and regard the surface of the Lake as level. The longest period of the Detroit tables, which correspond with those at Cleveland, was compared by the mean of both, which gave the elevation of the stone water table of the hydraulic tower above the Cleveland zero at three feet $\frac{48}{100}$ths. By Mr. Hathan's register this mark was, in June, 1838, three feet $\frac{20}{100}$ths above the surface of the river.

During the month of July, 1851, Mr. Lothrop, at Buffalo, and I myself, at Cleveland, kept registers. The fluctuations of this month were small, the weather being very calm. The high water line of June, 1838, by this comparison, corresponds to a depth of water in the enlarged canal of eleven feet $\frac{42}{100}$ths. The base of the hydraulic tower is, therefore, fourteen feet $\frac{88}{100}$ths above the bottom of canal.

TABLE OF WATER LEVELS

All the measurements reduced to one expression, which is the depth

Year.	Monthly Average.												Yearly change of level.
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
1788 to 1790	...	...	...	...	...	...	...	...	...	...	...	...	...
1796	...	...	...	...	...	...	...	...	...	...	...	...	...
1797	...	...	...	...	...	...	...	...	...	...	...	...	...
1798	...	...	...	...	...	...	...	...	...	...	...	...	...
1800	...	...	...	...	...	...	...	...	...	...	...	...	...
1801	...	...	...	...	...	...	...	...	...	...	...	...	...
1802	...	...	...	...	...	...	...	...	...	...	...	...	...
1806	...	...	...	...	...	...	...	...	...	...	...	...	...
1809	...	...	...	...	...	...	...	...	...	...	...	...	...
1810	...	...	...	...	...	...	...	...	...	...	...	...	...
1811	...	...	...	...	...	...	...	...	...	...	...	...	...
1812	...	...	...	...	...	...	...	...	...	...	...	...	...
1813	...	...	...	...	...	...	...	...	...	...	...	...	...
1814	...	...	...	...	...	...	...	...	...	...	...	...	...
1815	...	...	...	...	...	...	...	9.40	...	...	...	...	...
1816	...	...	...	...	...	...	...	...	...	...	...	...	...
1819	...	...	...	...	...	6.30	...	...	...	...	...	...	...
"	...	...	...	...	...	...	...	6.30	...	...	...	...	...
1820	...	...	...	...	...	...	...	6.30	...	...	...	...	...
1821	...	...	...	...	...	...	...	...	...	...	...	...	...
1822	...	...	...	...	...	...	...	...	...	...	...	...	...
1823	...	...	...	...	...	...	...	...	...	...	...	...	...
1824	...	...	...	...	...	...	...	...	...	...	...	...	...
1825	...	...	...	...	...	...	...	...	...	...	...	...	...
1826	...	...	...	...	...	...	...	...	...	...	...	...	...
1827	...	...	...	...	...	...	...	...	...	...	...	...	...
1828	...	...	...	...	...	7.30	...	7.80	...	...	...	...	...
1829	...	...	...	...	...	...	...	...	...	...	...	...	...
1830	...	...	...	...	...	...	...	...	...	...	...	...	...
1831	...	...	...	...	...	...	...	...	...	...	...	...	3.00
1832	...	...	...	...	...	...	...	...	...	...	...	...	...
1833	...	...	...	...	...	...	...	...	...	...	...	...	...
1834	...	...	...	...	...	8.82	...	...	...	...	...	...	...
1835	...	...	...	...	...	8.57	...	...	8.07	...	...	...	...
1836	...	...	...	...	...	9.82	...	9.82	...	...	...	...	...
1837	8.30	...	...	...	...	8.82	...	(10.07)	...	...	...	...	...
1838	...	...	...	...	10.39	(11.40)	11.15	10.64	10.10	9.89	...	9.46	1.94
"	...	...	...	...	...	...	...	(11.40)	11.16	10.41	9.31	9.40	2.09
1839	7.74	...	...	...	9.50	9.83	10.08	10.13	9.33	(10.30)	...	...	2.56
1840	6.92	...	...	8.33	8.37	8.42	(8.60)	...	8.11	8.04	7.84	7.61	1.68
"	...	...	...	...	10.33	(10.90)	10.33	10.40	9.30	9.10	...	...	...
1841	6.68	...	6.65	7.04	6.95	7.15	7.57	(7.99)	7.17	6.86	6.85	6.97	1.34
"	...	...	8.65	...	(9.50)	9.24	8.80	8.30	7.75	6.87	...	...	...
1842	8.99	...	...	...	9.50	...	...	...	...	...	...	...	...
1843	...	...	...	...	8.96	...	...	...	...	...	...	...	...
1844	...	...	...	...	9.21	...	...	...	...	...	...	...	...
1845	...	...	...	...	(9.30)	...	...	8.71	8.43	8.27	7.84	7.60	1.34
1846	7.34	6.97	6.91	7.30	8.26	(8.57)	(8.57)	8.34	...	...	...	...	1.66
1847	...	...	...	...	8.80	...	...	...	...	8.50	...	...	...
1848	...	...	...	...	8.46	...	...	...	...	8.94	...	...	...
1849	...	...	8.32	...	8.07	...	8.02	...	...	...	...	...	...
"	...	...	...	...	9.40	...	...	...	...	...	...	...	...
1850	...	...	...	...	8.96	8.49	...	...	...	...	7.71	7.83	...
1851	7.88	7.86	8.40	8.47	8.59	9.34	(9.46)	9.34	9.07	9.13	9.21	...	1.58
"	7.49	...	...	...	...	(9.49)	9.46	(9.49)	9.15	8.99	8.74	8.50	2.00
1852	8.35	8.07	8.42	9.47	10.07	(10.30)	10.20	9.97	9.61	9.35	9.10	9.07	2.23
1853	9.56	9.40	9.49	10.07	10.15	...	...	...	...	...	...	...	...
1856	...	...	...	...	...	...	...	...	...	...	8.30	7.90	...
1857	...	8.15	8.15	8.78	9.65	9.90	(10.15)	9.99	9.60	9.55	9.32	9.32	2.00
Mean	...	...	...	...	...	...	...	...	...	...	...	...	1.85

FOR LAKE ERIE.

of water on the Mitre Sill of the enlarged Erie Canal at Buffalo.

YEAR.	PLACE OF OBSERVATION.	OBSERVERS.	EXPLANATIONS, REMARKS, ETC.
1788 to	E. end of Lake	......	By tradition derived from the early settlers, very high; according to some as
1790	Erie	......	high as 1838, but this is doubtful.
1796	W'rn Reserve	......	By the first emigrants and surveyors, reported as very low—five feet below 1838.
1797	Buffalo	......	Rising rapidly; statement of a lake captain to De Witt Clinton.
1798	Cleveland	Alonzo Carter	Water continues to rise, but three feet below June, 1838.
1800	Detroit	......	Very high; old roads flooded; report of old people to Dr. Houghton.
1801	"	......	Still high.
1802	"	......	Very low; reported by old settlers as lower than 1797.
1806	Cleveland	......	Very low; reported by old settlers as lower than 1801-2, and declining regu-
1809	Detroit	......	larly to 1809-10, when it reached a level by many regarded as low as that
1810	Buffalo & Erie	M. Sanford	of 1819. Bird Island left bare and dry.
1811	Buffalo	A Lake Captain	Rise of six inches in the spring over 1810, by measurement, and a fall of two inches.
1812	"	"	Rise of fourteen inches in spring over 1810, by measurement, and a fall of three inches.
1813	"	"	Rise of two feet two inches in spring over 1810, by measurement.
1814	Erie, Pa.	Capt. Dobbin	Rise of two feet six inches in spring above general level of 1813.
1815	Detroit	Col. Whiting	Rise of three feet above average level of 1814; also M. Sanford and A. Carter.
1816	Cleveland	A. Carter	Water still high but falling, and continued to fall till 1819.
1819	Detroit	Col. Whiting	LOWEST WELL-ASCERTAINED LEVEL OF THE WATER IN LAKE ERIE, though it was
"	Black Rock	......	reported to have been 1.60 feet lower at Detroit in February, 1819.
1820	"	......	Old residents at Buffalo state, in August as low as 1819.
1821	"	Gen. Dearborn	Rising, as reported by Major Lachlan and Mr. McTaggart, of Canada.
1822	Cleveland	A. Carter	Rising; in the spring four feet below June, 1838.
1823	Canada	Mr. McTaggart	Rising; in the spring three feet three inches below June, 1838.
1824	Cleveland	......	Rising gradually.
1825	"	A. Walworth	Rising; lowest level three feet below June, 1838.
1826	"	A. Merchant	Rising; lowest level two feet ten inches below June, 1838.
1827	Canada	McTaggart	About the general level of 1815.
1828	Detroit	A. E. Hathan	
1829	"	Dr. Houghton	Water still rising. See geological report of Michigan for 1839.
1830	"	S. W. Higgins	General level same as 1828. Mr. H. was topographer of Michigan.
1831	"	Col. Whiting	Lower than last year; yearly change at least three feet.
1832	Cleveland	A. Walworth	General average two feet ten inches below June, 1838.
1833	"	"	General average three feet two inches below June, 1838.
1834	"	"	Mr. Wolworth was the first agent of the works at the harbor.
1835	"	"	
1836	Detroit	A. E. Hathan	Mr. Hathan was at the time city engineer.
1837	Buffalo	J. Lothrop	Mr. Lothrop was an engineer upon the Erie Canal.
1838	Cleveland	Geo. C. Davies	From July to October inclusive, measurements several times a day.
"	Detroit	S. W. Higgins	HIGHEST KNOWN LEVEL OF LAKE ERIE, occurring at Cleveland in June, and at Detroit and Buffalo in August of this year.
1839	Black Rock	Com. Advertiser	
1840	Detroit	A. E. Hathan	Occasional measurements.
"	Black Rock	Com. Advertiser	Measurements daily during the summer months by direction of the State Engineer.
1841	Detroit	A. E. Hathan	
"	Black Rock	Com. Advertiser	According to the Detroit register, the water in the Detroit River was com-
1842	"	"	paratively lower, during the whole of the years 1840 and 1841, than at Black
1843	"	"	Rock. In September and October, 1841, the two records agree.
1844	"	"	From 1838 to 1852, the Black Rock, Buffalo, and Cleveland figures are the mean of daily measurements.
1845	Cleveland	T.B.W. Stockton	Col. Stockton was the government agent for the works at the harbor, and
1846	"	"	caused the water level, the barometer, and thermometer, to be noted three times a day.
1847	Cleveland	......	The *Buffalo Commercial Advertiser* has occasionally published the results of
1848	Buffalo	......	the observations made at Black Rock, particularly for the month of May,
1849	Detroit	......	and sometimes all the summer months, but I have not been able to procure
"	Buffalo	......	the original record.
1850	"	John Lothrop	Mr. Lothrop was the engineer of the enlarged Erie Canal, western division. His zero is the mitre sill of the guard lock, Buffalo, which is one foot lower than the sill of the old guard lock of Black Rock.
1851	"	"	The agreement between the contemporaneous readings at Buffalo and at
"	Cleveland	C. Whittlesey	Cleveland, in the year 1851, is very close.
1852	"	B. Stanard	At Detroit, the lowest observed month since 1838, was March, 1841, 6.65; at
1853	"	C. Whittlesey	Black Rock, October, 1841, 6.87; and at Cleveland, March, 1846, 6.91.
1856	"	"	Greatest known difference at Detroit, six feet eight inches.
1857	"	"	Greatest known difference at Cleveland (about), six feet.
			Greatest known difference at Buffalo, fifteen feet six inches.
Mean			Greatest permanent difference of general level, five feet one inch.

Neither general opinion nor tradition can be reduced to feet and inches, and I have, therefore, discarded from the above table whatever depended solely upon the recollection of one person, who had taken no measurements or preserved no memoranda. There are, however, certain objects, such as roads, wharves, and buildings, that serve as points of reference for high and low water, and tend by association vividly to impress upon the memory facts of this character. The old French inhabitants of Detroit have no tradition of a water level below that of the year 1819, although Detroit has been occupied since 1702. At Buffalo the year 1810 is remembered as one of low water, nearly or quite as low as 1819.

In discussing the data here presented, it is apparent that the surface of the Lake is not strictly level, and thus there are discrepancies as to the time of high and low water at different places. The form of the coast at Buffalo is such that the height of water is affected by it in connection with certain winds. Those from the east and northeast keep back the waters, and cause a depression that may be observed for one or two months at a time. The reverse occurs with prevailing winds from the west and southwest. The waters driven eastward between two shores, constantly approaching each other, are raised above the general surface like the tides in the Bay of Fundy. On the 18th of April, 1848, it appears from the register of Mr. Lothrop that a gale from the northeast reduced the level of the Lake to a point fifteen feet six inches below the surface of October 18th, 1849, when a terrible storm occurred from the southwest. At Cleveland the greatest observed local fluctuation was three feet two inches, which took place on the 19th of November, 1845. As the Lake is broad opposite Cleveland, and the place is situated not far from the middle, its surface would be less affected by winds; and here the level during the summer of 1819 is regarded as the lowest.

But if that year did not differ from other years in the period of the annual rise and depression, it must have been still lower in the winter than in the summer months. Dr. Houghton has mentioned one observation, made some time in the winter of 1818 and 1819, by which the water in the Detroit River was six feet eight inches below the flood time of 1838. The winter season, however, has been little noticed, except by those who keep water tables; and at that time a regular register was not known.

For want of better data, the well noted low water in the summer of 1819 is compared with the great rise of the summer of 1838, two of the most remarkable years in the history of the fluctuations. In 1838, on the shores of Lake Erie, grounds were submerged on which old orchards had come to maturity, and on forest lands trees that were centuries old were killed by the overflow of the Lake water. In the month of June I observed small boats passing from house to house in the streets of the village, at the mouth of the Conneaut river, Ohio. The water rose at Cleveland, in the month of July, so as to cover the floor of a warehouse to the depth of one foot. These events served to revive the memory of past times, and to stimulate observation in coming years.

Among the old inhabitants it brought up afresh the popular idea derived from the aborigines, that the rise is periodical, occurring once in seven years. This belief is very generally entertained, and many persons related the several years when the rise occurred. This belief shows the tendency to hasty generalization, and the superstitious proneness to attribute to the number seven a peculiar applicability to the recurrence of natural phenomena.

By examining the table we have given, containing observations that have been made since 1819, there will appear a continual rise until 1838, a period of nineteen years, without any decline. Other tables show an uninterrupted decline from 1838 to 1841, three years; in 1841, a slight rise; from 1842 to 1851, a regular decline of eight years. During a space of thirty-two years, there is no instance of a return of high water in the period of seven years. For the years since 1838, I am able to offer a much more satisfactory exhibit. To simplify the result, I have constructed a diagram of curves whose ordinates are the monthly average of the surface reduced to the Buffalo zero for such months and years as have a good mean. There are four years complete, the means of which are consolidated into one curve, which is placed, to prevent confusion, below the other curves. See Plate I, No. 1.

The regularity of the annual rise and fall is evident from an inspection of the form of the curves. The months of June and July are high as compared with other months, whatever the general level may be. A depression follows immediately, which reaches the lowest points in the months of December and January. This is the law, to which there are exceptions, arising from variations of the seasons. In fourteen of the best ascertained years high water occurred in June and July ten times; in ten years, the annual decline reached the lowest point in the months of December and January six times. There is, therefore, a spring flood and a winter ebb, the same as in the Mississippi and other large rivers or ponds. The surplus water due to melting snows and spring rains causes an accumulation of water. In winter the frost and drought, by diminishing the supply, causes the surface to settle below that of summer. The amount of fluctuation within the year, deduced from sixteen years' observation, is as follows:—

	Feet.	Inches.
Cleveland, greatest average monthly difference of high and low water . . .	1	8
Detroit, " " " " . . .	1	2½
Buffalo, " " " " . . .	0	10½
Mean annual difference of highest and lowest months	1	1½

Lakes Huron and Michigan have not received much attention; but are known to have been high in 1838 and low in 1819. It does not necessarily follow that the highest or lowest level of different Lakes will occur at the same time, nor that the quantity of rise and fall should be the same. There should be, however, in all of them an annual flux and reflux, and also secular fluctuations. As the lower Lakes receive more water from those above during years that are high than they do when there is a depressed surface, there should be a greater range between high and low water in them than in those nearer the source of supply. Lake Superior is the only one of the chain that exhibits the effects of conditions strictly its own.

TABLE OF WATER LEVELS

Reduced to an expression of the depth of water

Year.	Average of the month in feet and inches.												Annual range.
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
1827–8	...	...	...	...	...	...	...	...	...	...	...	...	...
1838	...	...	...	...	...	...	...	...	...	...	...	...	...
1844–5	...	...	...	...	...	...	...	...	...	...	...	...	...
1846	...	...	...	...	...	...	...	...	...	...	...	...	...
1847	...	...	10	...	...	...	...	...	...	...	...	...	...
1851	...	...	...	...	...	...	...	...	(12 3)	...	...	...	...
1852	...	...	...	...	...	11 7	...	...	...	...	...	...	...
1853	...	...	...	...	9 11	10 7	11 0	10 6	(11 4)	11 1	...	10 9	...
1854	...	...	9 9	10 3	10 4½	10 9	11 2	11 4	11 6½	(11 9)	11 7	11 3	2 0
1855	11 1	11 2½	11 3½	11 3½	11 4½	12 1	12 6	12 10	12 10$\frac{1}{16}$	(13 2$\frac{5}{16}$)	13 0	...	2 1
1856	...	...	...	...	12 3	12 7	12 9	13 1$\frac{1}{16}$	(13 4$\frac{5}{16}$)	13 2$\frac{5}{16}$	...	...	...

Here the high water month, from the meagre observations hitherto made, is September; and the low water month is March. The streams are numerous, but short and rapid. Their waters soon reach the Lake in the spring, but to counteract this rapidity the season is late. Snow does not entirely disappear from the swamps and gorges of the mountains before the middle of May. The area draining into this Lake is small compared with its extent. There are but three considerable rivers: the St. Louis, Ontonagon, and Michipicoton, the longest of which does not exceed two hundred miles, yet Captain Bayfield states that more than ten times the quantity is received than is discharged at St. Mary's. On account of the small extent of the basin, the spring floods are insufficient to bring the annual rise to its maximum. It requires the additional rains of the summer and the early fall months to effect this. The observations are not sufficient to determine correctly the amount of either the annual or the secular variations. The greatest measured difference is two feet six inches, that is, from the high water of September, 1851, to the low water of March, 1854. The greatest difference of months in the year 1853, is one foot five inches; in 1854 two feet, and in 1855 two feet one inch.

All those who journeyed along the shores of this Lake in 1845–6, observed that the summer months were unusually dry. Fires raged in all parts of the country, not upon the mountains only, but in swamps which had been saturated with water so long that large cedar-trees had grown up and died of old age. In consequence of this the surface of the Lake declined in those years, and in 1847 still more—according to the general estimate three feet.

The position of Sault St. Mary's I am well aware is not a good one for ascertaining the actual changes that occur in the open Lake. For this purpose Copper Harbor, Eagle river, Rock Harbor on Isle Royal, or Ontonagon would be much preferable. Places on the broad parts of the water, and not at the heads of bays and inlets, are much the best points to observe the fluctuations of level. They

FOR LAKE SUPERIOR.

on the Mitre Sill, head of Canal, Sault St. Mary.

YEAR.	PLACE OF OBSERVATION.	OBSERVERS.	REMARKS.
1827-8	Sault St. Mary	Capt. Dearborn, U. S. A.	Reported to be at the lowest level.
1838	......	......	Reported by Major Lachlan as three feet higher than 1828.
1844-5	......	......	Water high in these years, but not measured.
1846	CopperHarbor	W. W. Mather, C. Whittlesey	From two to three feet below general level of 1845.
1847	"	W. W. Mather, Mr. Turrill	Rise from June to September, twelve inches; trees a hundred years old within four feet of the present level.
1851	"	D. D. Brockway	This being at the time the highest then known state of the water, a mark was
1852	"	Mr. Turrill	made on the rocks of Duck Island, near the end of Turrill's dock; this, by a comparison of seven months in 1855-6, corresponds to twelve feet three inches in the canal.
1853	Eagle River	C. Whittlesey	Mean of frequent observations during the month. Copper Harbor mark, or
1854	"	"	zero, transferred to the Eagle River dock.
1855	Sault St. Mary	Wm. Finney	Taken frequently during the summer months, under the direction of John
1856	"	M. B. Sherwood	Burt, superintendent of the canal.
			Highest water in September three times, in October twice, in five years.
			High months in parentheses.

are less affected by winds and currents, and the irregularities that arise from indentations of the coast. Whoever undertakes to compare observations made at the Sault St. Mary's, at Detroit, Buffalo, Niagara, and Ogdensburg, which are situated upon straits or outlets, will at once perceive that the range of fluctuation is greater than it is at Eagle river, Cleveland and Oswego, situated on the open water. There is between them a correspondence, but, from causes that are apparent, the changes of level at the same time may be greater or may be less upon the St. Lawrence, the Detroit, or the St. Mary's rivers than upon Lake Ontario, Lake Huron, or Lake Superior.

If the width of the Detroit river at Fort Gratiot is greater than it is at Detroit, a rise of a given number of feet in Lake Huron must result in a greater rise at Detroit, the channel being narrower and more compressed. This is known to be the case in the Niagara river.

Below the falls for many miles is a narrow gorge where the river is compressed into much narrower limits than it has at Black Rock, where Lake Erie discharges itself. While this Lake varies secularly, not to exceed six feet, the rise and fall in the gorge below the suspension bridge is reported to be fifteen and even twenty feet. But on Lake Erie and Lake Superior the best zero or line of reference is furnished by the guard locks of the Erie and the Sault St. Mary's canals, and although the position is not favorable in other respects, the zero is so convenient and well established that I have reduced all the registers for these Lakes to the same expression as those at the canals just named.

In June, 1855, soon after the completion of the canal at the Sault, connecting Lake Huron and Lake Superior, Mr. John Burt, the superintendent, caused his assistants, Messrs. Wm. Finney and M. B. Sherwood, to keep a register of the depth of water at the upper and at the lower locks. These have been kindly furnished me as late as the fall of 1856. They were not made daily but frequently during the month; the course and strength of the wind were recorded, with occasional observations of the barometer.

The mean elevation of Lake Superior above Lake Huron is not yet known, nor the precise difference of elevation at any one time.

It is evident that the mean elevation of Lake Erie, or any of the Lakes above the ocean, cannot be determined till the mean of its fluctuations are known. We call the height of Lake Erie five hundred and sixty-five feet above mean tide at Albany, because it was found to be so at the time when the Erie Canal was surveyed. But without knowing the state of the water at Black Rock or Buffalo at that day, it is evident there may be an error of two and a half to three feet.

The same may be said of all the Lakes. The rise to be overcome by the canal at the Falls of St. Mary's was reported by the engineers to be seventeen and one-half feet; but if there is a change of level in Lake Superior above the falls, it does not follow, as has been just observed, that the same change of level would be noticed below the falls where the river is wider.

Mr. Murray, of the geological survey of Canada, in 1848, examined the other rapids of the St. Mary's river, and made their united descent two feet $\frac{91}{100}$ths, which, added to the above and neglecting the descent of the water between the rapids, the difference is twenty feet $\frac{41}{100}$. As measured barometrically by Captain Bayfield, the elevation of Lake Superior is six hundred and twenty-seven feet above the ocean, and Lake Huron is stated by Mr. Higgins to be five hundred and seventy-eight, making a difference of forty-nine feet.

The elevation of Lake Huron is, however, subject to correction by future levels along the connecting straits. I have not, in this paper, given the details of the water tables, reserving them for publication within their respective States. The results are shown in the proper tables, in the form of a monthly average, with remarks.

The register of Messrs. Finney and Sherwood for the six summer months of 1855 and 1856, show a difference between the depth of water at the lower and at the upper locks of about ten inches during those years, as follows:—

	Feet.	Inches.
Mean depth of water at upper lock six months, 1855	12	9.00
" " " " 1856	12	10.25
lower lock six months, 1855	12	00.38
" " " " 1856	12	1.00

These tables show conclusively the effect of winds in raising and depressing the water in a narrow and crooked strait connecting two Lakes. On the morning of July 16, 1855, the wind was from the northwest, and off Lake Superior. As usual, in that case, the water rose at the upper gate, varying from twelve feet one inch to thirteen feet six inches, or about one and one-half feet.

At noon the wind had changed to the opposite quarter and blew from the southeast. The water fell to eleven feet five inches, and at one P. M. to ten feet nine inches, making a difference of two feet nine inches in less than eight hours.

On the 3d of June, 1856, the observers witnessed a still more remarkable change, because it occurred while the wind was steadily from the same quarter. It blew a continued gale from the southeast during the entire day. At 7½ A. M. the water was low. At 3½ P. M. it was still lower, being at nine feet nine inches, rising in the space of three hours to thirteen feet ten inches, a change of four feet one inch.

The highest monthly average is that of September, 1856, when the mean depth in the canal was thirteen feet four and $\frac{30}{100}$ inches. During the season of navigation the water of Lake Superior is higher than during the winter months, but a fall of four feet in the general surface of the Lake below the highest known state would reduce the canal depth in September to nine feet four inches, and might interfere with the passage of large craft.

At present the shallowest parts of the St. Mary's river are less than nine feet, but the canal was intended to have a depth of water of never less than twelve feet.

This is an instance of the importance of Lake registers to engineers and those engaged in improving navigation.

TABLE OF WATER LEVELS

All the measurements reduced to the zero, or line of reference, at

Year.	Monthly Average. Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly change of level.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
1795	...	...	...	...	...	...	...	...	...	...	...	...	3 0
1815	...	7 4	7 6	...	...	...	(6 8)	...	...	...	...	...	2 8
1816	...	...	6 10	...	...	(4 11)	(5 10)	...	...	...	...	...	1 8
1817	...	...	..	7 4	...	(5 6)	...	...	...	...	...	...	1 11
1818	...	...	8 3	...	...	(5 10)	...	...	...	...	...	...	1 10
1819	...	...	8 9	...	...	...	(6 10)	...	...	...	...	...	2 5
1820	...	...	...	8 4	...	...	(5 2)	...	...	...	...	...	1 11
1821	...	...	8 1	...	...	(5 10)	...	...	...	...	...	...	3 2
1822	...	...	8 0	...	...	(5 6)	...	...	...	...	...	...	2 3
1823	...	...	7 10	...	...	...	(5 4)	...	...	...	...	...	2 6
1824	...	...	9 4	...	...	(7 1)	...	...	...	...	...	...	2 6
1825	...	...	9 4	...	...	...	(6 10)	...	...	...	...	...	2 3
1826	...	...	...	...	...	(5 2)	...	...	...	5 10	...	...	2 6
1827	...	...	...	...	...	...	(2 10)	3 11	...	4 6	...	...	...
1837	...	...	...	...	...	...	4 6	...	...	5 1	...	...	...
1838	...	...	...	...	...	...	(3 0$\frac{1}{2}$)	...	3 11$\frac{3}{4}$	4 5	...	...	...
1839	5 5$\frac{1}{2}$	...	...	...	...	...	4 5	4 5$\frac{1}{2}$	4 10	5 4$\frac{1}{2}$	5 9	...	...
1840	...	6 3$\frac{1}{2}$	5 8	5 2	4 5$\frac{1}{4}$	(4 1$\frac{1}{2}$)	4 2	4 5	4 11$\frac{1}{3}$	...	5 5$\frac{9}{10}$	5 8$\frac{1}{10}$	2 3
1841	5 8$\frac{2}{10}$	5 9$\frac{4}{10}$	5 11$\frac{1}{2}$	5 2$\frac{7}{10}$	(4 6$\frac{1}{2}$)	4 6$\frac{8}{10}$	4 8$\frac{1}{2}$	5 1$\frac{1}{2}$	...	6 3	6 11$\frac{7}{10}$	7 0	2 5
1842	6 9	6 5$\frac{1}{2}$	6 2	5 10$\frac{7}{10}$	...	5 5	(5 2$\frac{7}{10}$)	5 7	5 9	6 1$\frac{2}{10}$	6 4$\frac{1}{10}$	6 6$\frac{6}{10}$	1 6
1843	6 5$\frac{9}{10}$	...	6 1$\frac{2}{10}$	6 6	5 3$\frac{1}{10}$	5 0$\frac{6}{10}$	(5 1)	5 6$\frac{7}{10}$	6 0$\frac{1}{2}$	6 1$\frac{1}{2}$	6 2$\frac{1}{2}$	6 5	1 5
1844	6 7	6 7	6 4$\frac{6}{10}$	6 1$\frac{6}{10}$	...	5 3	(5 2$\frac{8}{10}$)	5 4$\frac{9}{10}$	5 6$\frac{2}{10}$	6 5$\frac{1}{2}$	...	...	1 4
1845	6 7$\frac{2}{10}$	6 4$\frac{1}{2}$	...	5 1	...	(5 1)	5 5	5 10$\frac{6}{10}$	6 6	6 5	6 9$\frac{1}{2}$	...	1 8$\frac{1}{2}$
1846	7 5$\frac{1}{2}$	7 7	7 8$\frac{7}{10}$	6 7	6 4	6 4$\frac{2}{10}$	(6 1)	6 4	6 8$\frac{2}{10}$	7 1$\frac{1}{2}$	7 5$\frac{1}{2}$	6 7	1 8
1847	6 10	6 4	6 6	5 10	5 3	(5 1)	5 4$\frac{7}{10}$	5 11	5 10$\frac{7}{10}$	6 1	6 5	6 8	1 9
1848	(5 3)	5 8	6 5	6 0	6 2$\frac{1}{2}$	6 2	6 3$\frac{7}{10}$	6 5$\frac{1}{2}$	6 11$\frac{1}{2}$	7 3$\frac{8}{10}$	7 8$\frac{3}{10}$	6 8	2 5
1849	7 0	7 0	7 2	6 8	5 10	(5 9$\frac{1}{2}$)	5 11	6 4$\frac{1}{2}$	6 8	6 11$\frac{1}{2}$	6 7	6 3	1 2$\frac{1}{2}$
1850	6 7	6 2	6 2	6 2	(5 6)	5 6$\frac{1}{2}$	5 8	6 3$\frac{1}{2}$	6 9	6 10	7 5	6 5	1 11
1851	6 6	7 4	6 4$\frac{1}{10}$	6 9	6 6	(5 4)	5 9	5 6	5 10	6 9	7 3	7 1	2 0
1852	7 0	7 1	6 10	6 6	5 0	(4 5)	4 8	4 10	5 4	4 9	6 0	5 8	2 8
1853	5 9	5 6	5 6	4 11	4 6	(3 6)	3 9	4 3	4 8$\frac{1}{2}$	5 1	5 4$\frac{8}{10}$	5 6	2 3
1854	6 1	6 1	6 0	6 1	4 5$\frac{1}{2}$	(4 5)	4 8$\frac{1}{2}$	5 1	5 9	6 0$\frac{1}{2}$	6 6	6 10	2 5
1855	7 0	6 11	7 0$\frac{1}{2}$	6 9	6 0	5 9	5 1$\frac{1}{2}$	(5 1)	5 5	5 5	5 8	5 7$\frac{1}{2}$	1 11
1856	...	...	...	4 10	4 3	...	4 0$\frac{1}{2}$	4 4	5 2	5 5$\frac{1}{2}$	5 10$\frac{1}{2}$	5 11$\frac{1}{2}$	...
1857	...	6 0$\frac{1}{2}$	...	5 0$\frac{1}{2}$	...	3 8	(3 4)	3 5	...	...	...	...	...

The diagram of monthly variations for Lake Ontario (see Plate I, No. 2) is constructed from the register of H. T. Spencer, Esq., made once a month at the mouth of the Genesee river. A single reading for each month may fail to give a good average, but the regularity of the figures show that care was taken to avoid rough weather.

The table for Rochester is copied from the annual reports of the regents of the university. For a transcript of the registers at Oswego, I am indebted to M. P. Hatch, Esq., the harbor agent at that place. This includes a greater number of years, but except for the last two they are incomplete.

FOR LAKE ONTARIO.

Oswego, N. Y., reckoning downward from top of west pier.

YEAR.	PLACE OF OBSERVATION.	OBSERVERS.	EXPLANATIONS AND GENERAL REMARKS.
1795	Kingston	Mr. Weld	*Weld's Travels in Canada*, quoted by Major Lachlan. The lake reported to be higher than during the previous thirty years, or since 1765; its overflow destroying an orchard planted that year.
1815 1816 1817 1818 1819 1820 1821 1822 1823 1824 1825 1826 1827	F't Niagara " " " " " " " " " " " "	Edw. Giddings	Mr. Giddings kept a register while he resided at Fort Niagara from 1815 to 1827, but has published only the extremes of each year. The lowest water within the year occurred in the month of March nine times out of twelve, and the highest months during fourteen years are June and July, divided in equal numbers between them. The Niagara zero, or line of reference, was five feet below the top of the sill of the dock. To reduce his figures to the Oswego standard, the data are slight, but I have preferred to make the reduction, and thus exhibit all the measurements for this lake at one view. The only months of the Oswego and Niagara registers in common are those of July and October, 1838. By them, Mr. Giddings's line of reference was ten feet below the Oswego zero, and the top of the capsill of the dock five feet. Highest months of the year in parentheses. Mean of yearly fluctuations for twelve years at Niagara two feet three inches. HIGHEST KNOWN RISE.
1837 1838 1839 1840 1841 1842 1843 1844 1845 1846 1847 1848 1849 1850 1851 1852 1853 1854 1855 1856 1857	Oswego " " " " " " " " Oswego & Rochester " " " " " " " " Ogdensburg "	Lieut. R. C. Smead, U.S.A. " " J. W. Judson " " " " J. W. Judson & H. T. Spencer " " " " " M. P. Hatch & H. T. Spencer W. S. Malcolm W. E. Guest "	The Oswego zero, or line of reference, is the top of the coping of the west pier, near its southern end, at the boat-house, counting downwards to the surface of the water. Messrs. Smead, Judson, and Hatch were successively the agents of the government in the construction of the harbor at Oswego. Up to the year 1854, there are months in the Oswego register that are wanting, and these are supplied by reducing the measurements made since 1846 for the Regents of the New York University at Rochester harbor by H. T. Spencer. By a comparison of twenty months, common to both registers, Mr. Spencer's zero, or the top of the Rochester dock, is two feet ten inches below the Oswego zero. Prior to the time of Messrs. Hatch and Malcolm, the readings were made only occasionally in calm weather from one to eight times a month, but those gentlemen observed the water daily. In all cases, the mean of all the measurements is here given. Dr. Guest's observations at Ogdensburg extend from February, 1851, to August, 1857, made from time to time with occasional vacant spaces. By a comparison of eight months, his zero being the top of the railroad dock, is equivalent to eight and seven-tenths inches below the Oswego zero. The range of the fluctuations is about the same, and thus the descent of the river may be neglected for the purposes of this table. Mean of yearly fluctuations at Rochester and Oswego for eighteen years, one foot ten and a half inches. Highest water in the month of June eight times, July six, May twice, August once, January once. Lowest water in November three times, December twice, January three times, February twice, March three times. Greatest absolute height of all observations, July, 1838. Greatest absolute depression of all observations, March, 1824 and 1825. Greatest absolute difference at Niagara, six feet six inches.

By comparing the records of both places, it is plain that for such periods as are common there is a close correspondence. The two ports are about sixty miles apart, situated on the same shore, and at about the broadest part of the Lake. In the average of the seven last months of 1853 the greatest discrepancy occurs. The difference is six and one-half inches. On both registers the year 1853 is one of high and the year 1848 of low water. The year 1850, which is almost a blank in the Oswego tables, shows the lowest month of the Rochester records.

Mr. Edward Giddings, in a pamphlet published at Lockport, New York, in 1838, explaining his views upon the causes of the rise and fall in the surface of the

Lakes, gives to the public a part of his registers taken at the dock at Fort Niagara. The fluctuations of the Niagara river are not exactly coincident with those in the general surface of either the Lake above or the one below; but those reported by Mr. Giddings vary so little that I have reduced them to the same standard as the others and placed them in my abstract.

From the yearly average 1846 was the lowest, but differed only one-tenth of an inch from 1851. That portion of 1846 which appears in the Oswego tables shows the lowest stage observed there. Like Lake Erie, the spring rise is reached in the months of June and July; but there is more irregularity in the low water months.

According to Mr. Spencer's observations, high water occurred in the months of June and July, seven years in eight; the minimum of the year in the months of November and December, four times; January and February, three; and March, once. The records of nineteen years at Oswego show that the month of July, 1838, was higher than any month since, which corresponds in time with the noted flood on Lake Erie. From the high level of that year, the decline of Lake Ontario was not as rapid as Lake Erie. The lowest state since 1838 on the last named Lake is that of 1842, but on Lake Ontario that of 1848.

The question of the existence of a daily or lunar tide in this and other Lakes, corresponding to that of the ocean, has been, like the idea of a seven year's rise and a seven year's fall, so often brought forward that it deserves notice. In Weld's Travels in Canada, 1790–5, it is stated that "it is believed by many that the waters of Lake Ontario are influenced by a tide that ebbs and flows frequently in the course of twenty-four hours, as in the Bay of Quintè, where it has been observed to rise fourteen inches every four hours."

The same idea had its origin on Lake Michigan, at the head of Green Bay, which, like that of Quintè, is a narrow inlet extending far inland.

Colonel Henry Whiting, of the army, observed the fluctuations at Green Bay, in 1828, during the months of July and August, and states that in no case did they correspond to the passage of the moon over the meridian, and that there are no lunar tides. Mr. George C. Davies, who assisted Mr. Walworth in keeping a daily water table at Cleveland, in 1838, says, "I can say, without fear of contradiction, that there is no lunar tide on Lake Erie."

Captain Jonathan Carver, who passed through the Upper Lakes, in 1766–9, states that "observations made by the French at the Straits of Mackinaw show that there is no diurnal flood and ebb there."

The difficulty of reducing observations made at one port to those made at another, even on the same Lake, is owing to a want of correspondence in the rise and fall of water in the same months at different places. It is also impossible to free the readings from erratic "local oscillations," some of which are due to visible causes, such as winds and the shape of the coast, and others to causes not visible, and not yet well understood. This difficulty is apparent on comparing the means of the same months at different places on Lake Erie, as shown in the table of levels. We have for the years 1838, 1839, 1840, and 1841, pretty fair annual averages at

Detroit and at Buffalo. The mean annual average, however, is quite different, being greatest at the east end of the Lake.

MEAN ANNUAL DIFFERENCE FOR THREE YEARS.

	DETROIT. Feet.	BUFFALO. Feet.
1839 below 1838	1.33	1.25
1840 " 1839	0.99	1.25
1841 " 1840	1.00	1.65
Fall in three years	3.32	4.15

Between the highest and lowest months within the year, the extremes of fluctuation are also quite different at different places.

GREATEST DIFFERENCE OF LEVEL BY MONTHLY AVERAGES WITHIN A YEAR.

DETROIT. Feet.	BUFFALO. Feet.	CLEVELAND. Feet.
2.33	1.27	2.30

There is no way of eliminating such discrepancies, but by a more perfect series of observations, and the rejection of such as are affected by sudden causes. This cannot be done with the imperfect registers hitherto kept.

I now pass to the third class of "fluctuations," namely, transient fluctuations.

I shall here give some extracts from my memoranda upon the pulsations or oscillations that occur on Lake Superior, in calm as well as in stormy weather. Those of the 25th, 26th, and 27th of June, 1854, were very marked and regular.

The Lake for several days was without storms, winds, or waves. The first table is from observations made on the 29th of June.

Time of flood A. M.	Time of ebb A. M.	Period of reflux.	Time from flood to flood.	Extreme change of level.	REMARKS, WEATHER, &c.
11 h. 20 m.	11 h. 28 m.	8 min.	. .	5 inches	Calm; light rain.
11 33	11 38	5	13 min.	4 "	Light breezes off shore.
11 44	11 47	3	11	3 "	" "
11 50	11 55	5	6	Slight	Rain and wind increased.
12 1	12 5	6	11	3 inches	Stationary at ebb three minutes.
12 50	12 20	5	14	7 "	Slight wind off shore.

The same movement continued throughout the day. The place of observation was within the creek called Eagle river, about twenty rods from the Lake.

The flood or influx came into the stream, rapidly carrying boats, logs, and brush violently against the current as far as the rapids. No storms or severe winds occurred for several days before or after the 29th. The prevailing wind for the month of July was from the west. For two weeks in the latter part of June and forepart of July scarcely a day passed without the pulsations.

The next table is from my register for October 11, 1854. The play of the waters began early in the day, with a stiff south-easterly or off-shore breeze; and no waves visible along the shore line. The observations were made in the open Lake, at the pier, in three feet of water, eight rods from shore.

Time of flood A. M.	Time of ebb A. M.	Time elapsed ebb to flood.	Time elapsed flood to flood.	Range of level.	WEATHER, &c.
...	7 h. 35 m.	...	...	10 inches	Water calm.
7 h. 43 m.	7 46	8 min.	...	18 "	A current down the lake one
7 50	7 58	4	7 min.	18 "	mile per hour.
8 00	8 3	2	10	15 "	
8 13	8 19	10	13	Slight	
8 24	8 25	5	11	18 inches	Very sudden.
8 26	8 30	1	2	2 feet	
8 36	8 43	5	10	Slight	
8 46	8 53	3	10	...	
8 58	8 00	5	12	...	

The same southerly breeze and cloudy weather existed at the close as at the commencement.

The coast is visible from the pier each way one-fourth of a mile, over a clear sand beach.

At the moment of each influx a low wave broke on the shore along the whole field of view, and at each depression the water retired from one to three rods on the beach. This occurred everywhere at precisely the same instant. It had the appearance of a succession of undulations too slight and broad to create a visible swell on the surface coming directly upon the shore. The waves must have been parallel to the coast line and not oblique to it, or they would not have arrived at the same moment. If the crest of the undulations made an angle with the shore, the breaking of the water would have been progressive along the beach, as in the case of oblique waves.

Both the flood and ebb occurring as nearly as I could determine along a line of half a mile in length at the same time, the swell must have moved directly toward shore. On the 2d and 3d of this month (October, 1854) a destructive storm occurred, beginning at the east, changing to northeast and north, and finally to northwest, with heavy rain.

On my return to the Lake in the afternoon of the 11th, the movement was as active as in the morning. There had been no cessation during the day.

RECORD OF FLUCTUATIONS. October 11th, 1854.

Ebb P. M.	Flood P. M.	Ebb to flood.	Flood to flood.	Change of level.	REMARKS.
3 h. 25 m.	3 h. 26 m.	1 min.	...	1 ft. 2 in.	Weather calm; cloudy and rain.
3 33	3 35	2	9 min.	0 4½	
3 38	3 39	1	4	0 1	Observers Dr. S. H. Whittlesey
3 41	3 44	3	5	0 10	and James S. Morgan.
3 51	3 55	4	9	1 2	
3 58	3 59	1	4	0 7	
4 4	4 7	3	8	1 2	
4 11	4 17	6	10	0 11½	

This table shows greater rapidity of movement than that for the morning. The readings were made in the creek at the usual place, where the range from high to low level, as might be expected, was somewhat less than in the open Lake at the pier. As a general rule, it will be observed that the pulsation which is longest in its period from high to low, is the greatest in its range; but to this there are exceptions. On the morning of the 12th the water was still in motion, as it was the evening before, the weather being very calm, with a ground swell, coming in from the open Lake. At eleven o'clock A. M. it increased in rapidity, and in the range. About the 14th of the same month, another severe gale set in from the northwest, and continued three days. The remainder of the month was calm.

In the year 1855, the first oscillations of the season were noticed on the 20th of June, at 10 o'clock A. M., the weather being calm and clear.

The same thing occurred in the same kind of weather on the 26th, and again on the 13th of July. Hitherto, since the 22d of April, when the Lake ice broke up, there had been no prolonged gales nor storms, and only a few thunder-gusts. On the 14th, 15th, 16th, 17th, 18th, 19th, the movements were almost continuous. At the Sault, as Mr. Emerson informs me, the water rose three feet three inches on the 18th. The weather was cloudy and rainy, with frequent thunder-storms; but the Lake was calm most of the time. From the 24th to the 31st fluctuations occurred daily, with close, calm, cloudy, and foggy weather, the thermometer at night varying from 55° to 88° F.

From the 1st to the 12th of August, inclusive, there was no cessation of the oscillation, except for parts of two days. During this time there was but one gale, which was from the west, on the 9th instant, and lasted twenty hours. Thunder-storms were frequent, between which the sky was clear and the Lake calm.

I did not notice any more till the 25th of August. In the meantime the autumn winds had set in. During the afternoon of the 25th a violent thunder-storm arose from the northwest, and the oscillations came on as rapidly and as marked as at any period of the summer. Again, on the 30th and 31st the same thing occurred in calm weather, a thunder-storm having taken place during the intervening night. This phenomenon was observed in the month of September on eleven different days, and three times during the first eight days of October; after which, my residence having been changed, the observations ceased.

The month of September on this Lake and on Lake Erie was more stormy than the month of October. Whether these movements occur in the winter season, I am unable to say.

For the purpose of furnishing memoranda covering as wide a space as possible, I insert two more tables of an hour's readings each, one on the 2d, and another on the 3d of August, 1855, in different parts of the day.

OSCILLATIONS. August 2d and 3d, 1855.

Ebb A. M.	Flood A. M.	From ebb to flood.	From flood to flood.	Change of level.	REMARKS.
8 h. 23 m.	8 h. 31 m.	8 min.	. . .	0 ft. 3 in.	Weather calm; sultry, cloudy; movements continue all day.
8 36	Wanting	. . .	. . .	0 6	
8 49	8 53	4	. . .	0 5	
9 2	9 7	5	14 min.	0 4	
9 14	9 17	3	10	0 3	
9 25	9 29	4	12	0 4	
Aug. 3d, P. M.	P. M.				
. . .	1 h. 5 m.	. . .	. . .	. . .	Thunder-storm and rain in the morning; wind N. W., changing to S. in the afternoon; movements all day.
1 h. 7 m.	1 12	5	7	0 4	
1 16	1 20	4	8	0 2½	
1 30	1 37	7	17	0 4¾	
1 44	1 51	7	14	0 4	
1 54	1 56	3	5	0 3¼	
2 00	1 4	4	8	0 2½	

Such agitations of the water, in perfectly calm weather, attracted the attention of travellers at an early day. The relations of the Jesuit fathers are replete with accounts of sudden waves and swells, on which their canoes were tossed by some invisible agent. All those who reside on the shores of the Lakes have made the same observations. They have been so frequently noticed, and so often commented upon in the public prints, that the subject has ceased to excite surprise. Even the small Lakes of the interior sometimes exhibit the same mysterious movements, and at times when neither storms nor winds are within view. But notwithstanding the notoriety which they have acquired, there has been little direct observation. I know of only two instances in past time in which registers have been kept.

When General Cass was at Green Bay in 1820, he caused the flux and reflux of water at the mouth of the Fox river to be measured by a gauge set upon the shore. He concluded that the fluctuations of level at that place had no connection with lunar tides, and the observations show that they are not of the class which I have recorded.

The Eagle river tables show a uniformity and rapidity of motion quite different from the Green Bay registers. Without going into details upon the nature and cause of the changes of level at Green Bay, I will remark that a residence of one summer at Fort Howard confirmed me in the correctness of the conclusion of General Cass, in regard to the absence of any apparent effect from lunar attraction. This appears to be the case in an estuary, whose shores terminate at an acute angle, where very slight movements in the bay were made conspicuous at the point of intersection of the shore lines. The general form of Green Bay is such that the winds and currents of the open Lake affect its surface from whatever direction they come. The discharge of water from the Fox river is considerable, and the meeting of a wave of influx from the bay with this current would create an observable rise. Vibrations would follow, which should occur as they are observed to do, at irregular intervals of from half an hour to several hours.

The only records relating purely to "barometrical waves," that I know of, are those of Professor Mather, made at Copper Harbor in July, 1847. He compared, during one day, the fluctuations of his barometer, with those of the level of the water. The opinion has been so often advanced that these oscillatory movements are due to rapid variations of the barometrical pressure, that the term of "barometrical waves" has come to be their received name. It is doubtful whether, if this be the case, a mercurial barometer would show them. The movements of the column are too sluggish, and the apparatus for reading too imperfect to indicate a change of pressure that sometimes occurs in the space of one minute. My tables show that an oscillation may be completed in that time. Some more sensitive instrument is needed to indicate atmospherical changes that occupy at intervals of so short a period.

Professor Mather's observations were taken under circumstances that should be well considered in comparing them with others, made in calm weather and on the open Lake. (See Plate II, No. 3.)

Copper Harbor is a long narrow inlet, within which the movements are augmented, and may also be broken up, by counter waves reflected from the sides. During the time of Prof. M.'s observations, violent storms and winds were raging at the harbor, or were visible in the distance. Such agitations of the atmosphere, although they do not prevent the regular oscillations, would materially interfere with them. His observations were carefully made, and are the earliest exact data of a scientific kind relative to this subject within my reach.

There is to be found, moreover, in the geological reports upon the Upper Peninsula, a comprehensive historical notice of these phenomena.

Whether such movements have been observed upon the ocean, I am not aware. But it would seem probable, that, whatever the cause may be, it should be universal, and produce its effects on all bodies of water.

It is plain, after the barometer recovered from the effects of the tornado in the forenoon, it declined regularly till night, as might have been expected from the stormy condition of the weather.

The pulsations within the harbor continued all day, although there is a break in the readings from 11 A. M. till 2 P. M., with the exception of one at twelve hours eight minutes. So far, therefore, as these observations indicate, there is no apparent connection between the oscillations and the barometrical pressure; at least the movements for twelve hours were very marked, while the barometer was regularly falling, except during the tornado. The day commenced with the barometer at 29.288, and closed with it at 29.150.

In the autumn of 1856 I had the first opportunity of comparing the state of the barometer with the movements of the water. It was done with an aneroid recently compared with a good cistern barometer. I had not assistants to enable me at the same time to note the actual range of the wave in a vertical direction; but in this respect it was apparently the same as is shown in the preceding tables.

On the 19th of October the Lake was calm, a light breeze blowing off shore from the southeast. The weather was calm and foggy on the 20th, with a gentle breeze from the south, and a hazy, warm atmosphere, like the Indian summer. It rained during a greater part of the night between the 20th and 21st, and on the morning of the last named day the wind was northeast by east, or about parallel with the coast line. During the day rain continued to fall, and the wind, continuing in the same quarter, increased to a gale, raising a heavy swell upon the Lake. The oscillations were visible early in the morning, and continued with unusual rapidity all day. It was not until late in the afternoon that a barometer could be procured.

The readings were made at the moment of the culmination, and also at the lowest ebb of the wave or oscillatory movement. The results agree in general with those of Professor Mather, and show a steady motion of the barometrical column in one direction during the fluctuations of the water level.

REGISTER OF BAROMETRICAL READINGS TAKEN AT THE MOMENT OF THE EBB AND FLOOD.

Eagle River, Lake Superior, October, 1856.

Day and hour.	Reading of the barometer.	State of the pulsation.	STATE OF THE WEATHER—REMARKS.
October 21st	Inches.		
4h. 50m. P. M.	29.440	Ebb	Wind northeasterly, a moderate gale, with a drizzling rain.
4 51	29.445	Flood	
4 55	29.451	Ebb	
4 57	29.453	Flood	Extreme fluctuations, four to twelve inches.
4 58	29.460	Ebb	
4 59	29.470	Flood	Heavy swells, rolling into the creek, interfere with the regularity of the oscillations.
5 1	29.475	Ebb	
5 3	29.480	Flood	
5 4½	29.489	Ebb	
5 6	29.500	Flood	
5 7	29.500	Ebb	
5 8	29.500	Flood	
5 10	29.500	Ebb	
5 11	29.510	Flood	
5 13	29.510	Ebb	
5 13½	29.510	Flood	
5 14	29.510	Ebb	
5 15	29.510	Flood	
5 16½	29.510	Ebb	
5 18	29.520	Flood	
5 19	29.520	Ebb	
5 20½	29.520	Flood	Movements very strong.
5 33	29.535		Darkness sets in; oscillations continue till 9 P. M., and probably all night.
5 40	29.546		
6 00	29.575		
6 10	29.582		
6 20	29.595		
6 30	29.600		
6 40	29.595		
6 50	29.602		
7 00	29.600		
7 10	29.602		
7 20	29.602		
7 30	29.603		
7 40	29.601		
7 50	29.601		
8 00	29.600		
8 30	29.505		
9 00	29.601		Oscillations continue.
October 22d			
6h. 45m. A. M.	29.500		Wind north, light; oscillations going on, but the movements are slight; water calm.
7 15	29.485		
8 15	29.500		
8 45	29.500		Fog on the adjacent mountains.
9 15	29.500		Oscillations languid, but with a great vertical range.
9 45	29.500		

REGISTER OF BAROMETRICAL READINGS—Continued.

Day and hour.	Reading of the barometer.	State of the pulsation.	STATE OF THE WEATHER—REMARKS.
October 22d	Inches.		
11h. 00m. A. M.	29.510		
11 30	29.510		Weather same as in the morning.
12 00 M.	29.525		
1 00 P. M.	29.510		Wind north, increasing; no movement.
2 00	29.490		
3 00	29.480		Oscillations commence.
3 10	29.480		
3 15	29.500	Flood	
3 20	29.495	Ebb	
3 28	29.500	Flood	
3 45	29.500	Ebb	
3 48	29.510	Flood	
4 00	29.512		Movement ceases.
4 30	29.515		Wind north, light.
4 45	29.520		
5 00	29.525		
5 15	29.525		
5 45	29.570		
7 00	29.600		From 4 to 9 P. M., weather clear, cool, and calm, and no movement in oscillation.
8 00	29.600		
9 00	29.600		
October 23d			
7h. 00m. A. M.	29.640		Clear and cool; light breeze from the north; oscillations ranging from four to six inches.
8 00	29.725		
9 00	29.770		
9 33	29.775	Flood	Very full.
9 38	29.775	Ebb	Breeze lulls.
9 42	29.780	Flood	
9 47	29.785	Ebb	
9 53	29.785	Flood	Movement very slight.
9 55	29.785	Ebb	Movement very slight.
9 59	29.790	Flood	Very full.
10 3	29.790	Ebb	Slight.
10 8	29.795	Flood	
10 13	29.796	Ebb	Very low.
10 17	29.797	Flood	
10 20	29.797	Ebb	
10 25	29.797	Flood	Movement dying out.
10 32	29.785	Ebb	Movement dying out.
10 45	29.785		Movement ceases.
11 30	29.790		The general level of the lake is four inches lower than yesterday, but the vertical range of the pulsations is greater.
12 00 M.	29.780		
12 10 P. M.	29.780		
12 15	29.785		
12 20	29.802		
12 23	29.820	Flood	
12 30	29.830	Ebb	
12 35	29.840		No movement.
12 40	29.850	Flood	
12 45	29.855	Ebb	
12 50	29.860		Wind freshening from the north; movements succeed each other rapidly, but with a very slight rise and fall.
1 15			
1 30			
3 00			
3 30			Observations cease.

To the facts here given I propose to add very little in the way of a discussion. During the observations, embracing parts of three days, the barometer was lowest at the commencement, on the 21st. There had been no recent storms. The weather was close, foggy, and warm for the season and the latitude. From 4 o'clock and 50 minutes in the afternoon of the 21st to 9 o'clock in the evening, the rise was from 29.440 to 29.600. After a drizzling, foggy night, and a scarcely perceptible northerly breeze, the column stood about as it did the evening previous, and so remained until 3 P. M. of the 22d. The movements of the water were not marked till about this hour, when the wind, still continuing in the north, increased slightly, and the mercury began to rise.

On the morning of the 23d it was still higher, and the play of the waters very lively, the wind continuing in the north. So long as the observations continued, the movements of the surface were slight in quantity, but rapid in time, with only a slight wind. The barometer was all this time steadily rising. From 7 A. M. to 3 P. M. it rose from 29.640 to 29.870 inches.

For several days following the 23d there were moderate gales on the Lake, and rain. On the 28th of the month the regular autumn winds commenced, with snow. The middle day (the 22d) showed more fluctuation of the barometer and less of the water than either of the others.

It is not easy to conceive of a change in the weight of the atmosphere that shall be completed in an average period of ten minutes, and in some cases much less. Is not the cause therefore still to be sought for?

By my observations there is no apparent connection with storms, except thunder-storms. That season of the year, and the kind of weather when thunder-gusts are most frequent, with intervening calms and fogs, is most prolific of oscillations.

There is a distinct class of movements due to the direct driving force of winds that I shall notice below. For the consideration of those who wish to theorize upon the facts I have presented, I suggest that they turn their attention to the agency of electricity.

In May, 1855, the surface of Seneca Lake, as reported in the Geneva Gazette, rose and fell during two entire days as often as once in ten to thirty minutes, ranging through a vertical distance of five inches to two feet. The presence of storms is not mentioned. Could a difference of barometrical pressure exist on different sides of a narrow inland Lake only a few miles across? If so, can we rely upon the barometer to obtain difference of elevation?

While observing the influx and reflux at Eagle river, in July, 1855, the air was frequently agitated by the usual detonations of lightning. Shocks in the atmosphere which produce thunder, which stunned the ear, and cause walls and floors of buildings to tumble, might also produce agitations of the surface of water. There is physical force sufficient in the electricity of the atmosphere at all times to produce this effect; the difficulty occurs in applying it. Electrical movements may be brought into existence by opposite conditions of the atmosphere which rests upon the water and the surrounding shores, especially if there are adjacent mountains.

Vapor is condensed by winds which meet with peaks or mountain crests, and rain and thunder-storms are produced in this way. A breeze from the water pressing against the side of an abrupt highland chain frequently causes its summits to be enveloped in fogs and clouds of condensed moisture. Fogs excite electrical action like clouds, though with less intensity. Winds and unequally heated bodies of air may produce the same effect, causing rapid undulations in the atmosphere, and these may be transmitted to the water beneath.

Without offering this as a satisfactory explanation, I present it for consideration. To discuss the question rationally, we need observations upon the electrical state of the atmosphere during a period of oscillations.[1]

Upon fluctuations caused by winds it will not be necessary to enlarge, as they are produced by a visible cause, and little is left for speculation. The mechanical power of winds, heaping up water on a lea and depressing it on a windward shore, is generally known. On the North American Lakes the registers show that it is a force worthy of attention where the construction of harbors and piers is concerned. In such cases there must be added to the general stage of water something for the temporary rise due to storms.

Certain winds cause at the same place a greater rise than others. At each port the amount of this kind of fluctuation is shown by the daily registers for each direction of the wind. I select some instances from the tables in my possession, choosing from among those on Lake Erie only such as were registered three times a day, and on Lake Ontario once a day.

Those at Cleveland are from Colonel Stockton's observations; those at Buffalo from Mr. Lathrop's; and at Oswego they are taken from those of Messrs. Hatch and Malcolm.

[[1] The simplest hypothesis for the explanation of these phenomena is, that they are produced by the passage of thunder-storms, and perhaps, in some cases, of water-spouts, across distant parts of the Lake. It is well established, by observations at this Institution, that rapid oscillations of the barometer are produced during the passage of a thunder-storm across the meridian of this city. The mercury suddenly descends, then rises a little, and again falls, and after this regains its former level as the storm passes off to the east. A thunder-storm, therefore, crossing the lake at a distance, would transmit to the place of observation undulations from every point of its path, and these, arriving in succession, would produce effects similar to those described. This hypothesis can be tested by the observations which are now about to be established along the lake.—SEC. SMITHSONIAN INSTITUTION.]

TABLE SHOWING THE GREATEST CHANGE OF SURFACE WITHIN A MONTH ARISING FROM THE EFFECT OF WINDS.

CLEVELAND.		BUFFALO.		OSWEGO.	
Date.	Extreme change.	Date.	Extreme range.	Date.	Extreme range.
1845	Ft. In.	1850	Ft. $\frac{1}{100}$.	1854	Ft. $\frac{1}{100}$.
August	0 10	November	2.70	June	0.35
September	1 1	December	4.60	July	0.45
October	1 2	1851		August	0.90
November	2 0	January	5.55	September	1.00
December	2 5	February	5.60	October	0.65
1846		March	2.90	November	0.50
January	1 5	April	6.25	December	1.00
February	1 3	May	5.20	1855	
March	1 0	June	1.30	January	0.42
April	1 6	July	1.50	February	0.35
May	1 0			March	0.70
June	0 8			April	1.00
July	0 10			May	0.60
August	2 11			June	0.65
				July	0.20
				August	0.40
				September	0.30
				October	0.35
				November	0.70
				December	0.60
				1856	
				January	0.40

There are at each of these places momentary floods and subsidencies that exceed the recorded range of the surface, of which memoranda are made, and which I have already given.

In water tables, the object of which is to ascertain an average level for each month and for each year, sudden movements are avoided as much as possible. They are noted in the column of remarks, but do not enter the general average.

The table of extreme fluctuations just given represents, therefore, more properly the effect of such winds or storms as prevailed for some hours or days in one direction, rather than the result of sudden gusts producing impulses that pass away as suddenly.

The monthly range is far greater at Buffalo than at Cleveland, for reasons already given.

At Oswego it is less than at any place on Lake Erie, owing, probably, to a greater depth of water, especially near the shore.

For the port of Cleveland, Ohio, in twenty-one cases of high water—the wind was northeasterly, eight; northwest, three; south, three; and the remainder calm. At Buffalo, in six cases out of nine, it occurred under the influence of a southwest or down Lake breeze; and in the same number of instances of lowest water, the wind was from the east, or up the Lake, six times.

At Oswego the effect of winds is equally apparent, but the amount of fluctuation produced is less. In twenty-one cases—the highest water happened with a west wind, fifteen times; northwest, once; southwest, once; and south (or off shore), once. Lowest water occurred under a westerly breeze, four times; and with southerly (or off shore) winds, ten times; northerly, four; and in calm weather, twice.

At Cleveland, therefore, northeast winds pile up the waters more than any other. At Buffalo southwest, and at Oswego the west winds produce the same effect.

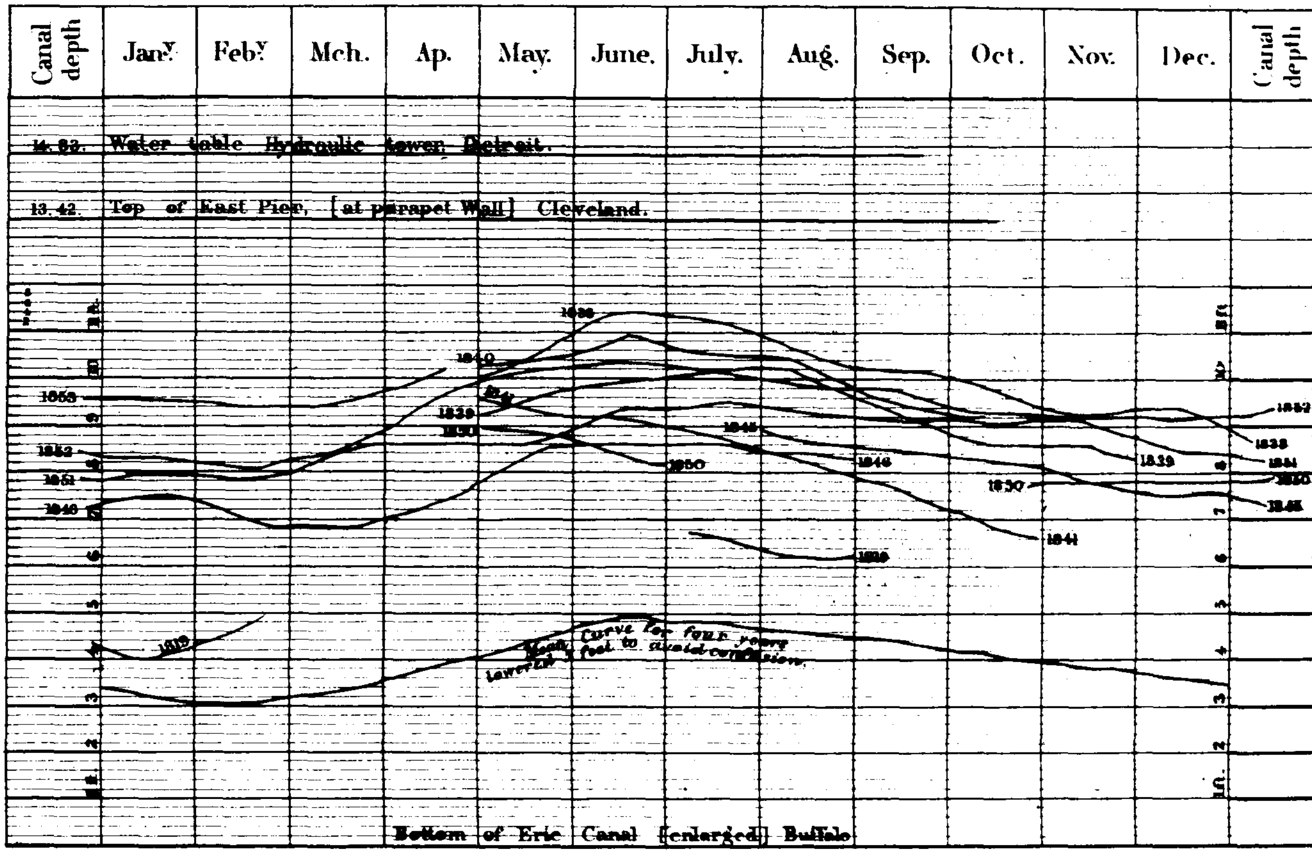
REGULARITY OF THE RISE AND FALL.

To show more perfectly the regular progress of the changes of level within the year, I have divided the observations for a few months into weeks, and constructed curves accordingly. For Buffalo I have selected two months in a rising stage of water, and for Cleveland five months in a falling stage. With these remarks the diagram will be understood. (Plate II, number 4.)

DIAGRAM.

showing the mean monthly height of water in LAKE ERIE as determined by daily measure-ments at different points, reduced to the depth of water in the ERIE CANAL at Buffalo. N.Y.

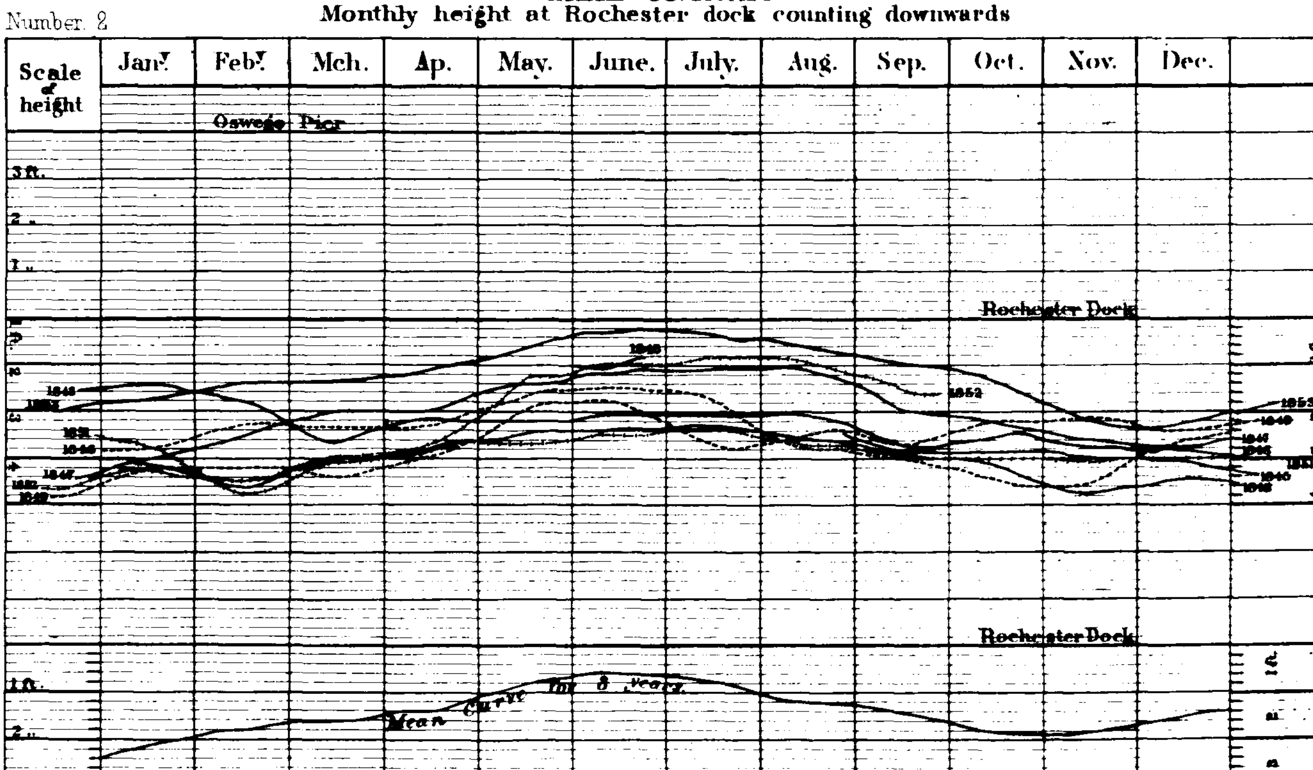
Number 1



LAKE ONTARIO

Monthly height at Rochester dock counting downwards

Number 2



T. Sinclair's lith. Phil.a

COMPARISON
of the transient oscillations with the
MERCURIAL COLUMN.

Prof. Mather. Copper Harbor. July 15 1847.

Number 3.

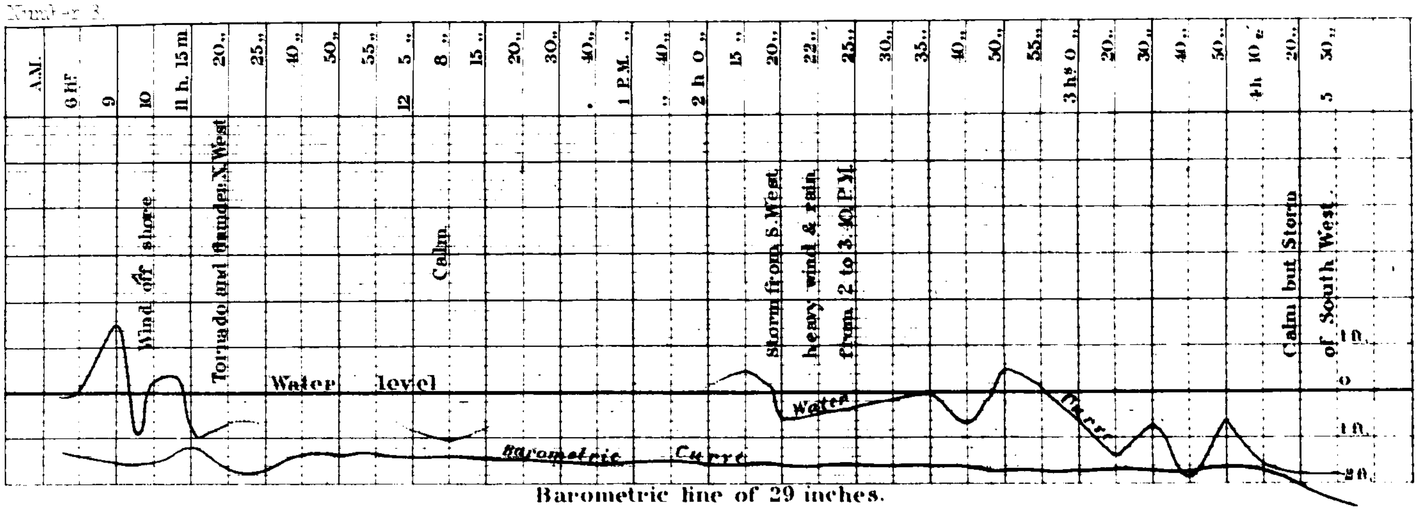


DIAGRAM
Showing the regularity of rise and fall by the WEEKLY AVERAGE
reduced from registers made three times a day.

WATERS of LAKE ERIE.

Number 4.